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COMMUNICATION PROCESSING DEVICE

Cross-Reference to Related Applications

This application is a continuation-in-part application of U.S. Application No. 09/228,015, filed 11 January 1999.

Background

This invention relates to processing of digital communication.

Communication processing devices are used in data and telephone communication systems, including wide area data communication networks, telephone networks, satellite communication networks, in-vehicle automobile communication systems, naval communication systems, home appliances, and retail devices. In the context of the description that follows, a communication processing device is almost any device that accepts and processes input flows of information and as a result acts on the input flows or produces output flows of information from those input flows. Communication processing devices may be implemented in software or as special purpose hardware, or using a combination of software and special purpose hardware. Examples of communication devices include data routers, which take input information flows and produce output information flows, and multimedia terminals, which take input information flows and acts on those input flows to present multimedia information to a user.

Operation of communication processing devices is typically specified in a variety of ways. In particular, the communication protocols used on the input and output flows are often specified in communication standards written in English or some other "human" language, possibly augmented using diagrams and picture. The operation of the devices typically focuses on the communication protocols used on the input and output flows. These specifications are then used as the basis of software implementations (e.g., in C, C++, Assembler, FlexLogic description) or as the basis of circuit designs.

Summary

In one aspect, in general, the invention is a method for processing a data signal, for instance, a data signal encoding a data bit stream which carries a sequence of data packets. The method includes accepting a protocol specification that includes specification of a number of elements, each specification including a length and a name, and optionally internal structure and actions. For instance, the elements are sub-packets or data fields. The method also includes accepting a series of data packets and for each accepted packet, associating portions of the input packet with elements specified in the protocol specification. For each of the associated portions of the input packet, the method includes performing actions included in the specification of elements associated with that portion of the input packet, for example by use of a subroutine call or passing a data message..

The invention can include one or more of the following features:

The specification of an action includes a specification of a programming language statement, such as a C++ statement, and wherein performing actions included in the specification of elements includes executing the programming language statement.

The method includes processing the protocol specification to produce executable software, and execution of the software implements the functions of associating portions of input packets with elements specified in the protocol specification and performing actions associated with elements specified in the protocol specification.

The protocol specification includes an object-oriented specification of elements, wherein names of components of an element are local to that element.

The protocol specification includes an association of numerical values and symbolic names for an element.

The method of can include processing the protocol specification to produce a hardware description, and wherein performing actions included in the specification of elements includes sending a message identifying a specified action.

Aspects of the invention include one or more of the following advantages.

By specifying a packet format using a formal, unambiguous language, various hardware and software based implementations can be automatically formed without the risk of introducing human error.

Implementations for different target environments, can be produced by processing the same protocol specification, thereby reducing human effort.

Specifying a protocol using a formal, unambiguous language allows development of completely unambiguous protocol standards, and therefore offers true interoperability between implementations of such developed standards.

The formal language allows development and implementation of complex protocols, in part because the specification is concise and includes built-in error handling capabilities. Furthermore, the language can be used to directly specify hardware protocol processors, for example, including direct solution trees for the specified communication protocol.

A protocol specification written in this formal language can be used to automatically build of configure test systems for devices that communicate using the protocol, and to automatically build or configure communication analyzers which monitor communication according to the protocol.

Multiple different protocols specified according to the formal language can coexist in a single implementation.

Other data series or information streams can also be processed according to a protocol specification. For example, chemical analysis sequences or DNA sequences can be processed according to the invention.

Other features and advantages of the invention are apparent from the following description, and from the claims.

Description of Drawings

FIG. 1 is a first general view of a communication processing device that makes use of a packet decoder to process a sequence of input packets;

FIG. 2 is a second general view of a communication processing device that makes use of a packet decoder to process a sequence of input packets, a packet generator to create a sequence of output packets, and a state machine coupled between the packet decoder and packet generator;

FIG. 3 illustrates a procedure for generating executable software for a software-based communication processing device, and shows a block diagram of a communication processing device;

FIG. 4 is a logical block diagram of software modules of the executable software used in a software-based embodiment;

FIG. **5** illustrates an exemplary packet structure;

FIGS. **6A-B** are a protocol specification for the exemplary packet structure;

FIG. **7** illustrates a particular type of information element packet;

FIG. **8** is a protocol specification of the particular type of information element packet;

FIGS. **9A-G** contain exemplary source code that is generated from a protocol specification; and

FIG. **10** is a tree-structured representation of a protocol.

Description

1 SYSTEM OVERVIEW (FIG. 1)

Referring to FIG. **1**, in a first general view of a number of alternative embodiments of the invention, a communication processing device **100** accepts and processes a data signal **125**. Data signal **125** is first segmented into a packet sequence **115** by a packet detector **120**. Each of the packets in packet sequence **115** is processed in turn by packet decoder **110**. Packet decoder **110** processes the packets according to a protocol specification **140**, which includes definitions of one or more packet types. These definitions include the structure and meaning (syntax and semantics) of the packets, as well as the required actions to take when various elements of the packets are present. For each packet that it processes, packet decoder **110** performs actions that are specified in protocol specification **140**. In this embodiment, packet decoder **110** produces zero, one, or more parameterized messages **135**, or other types of signals, that it passes to a message processor **130**. Message processor **130** makes use of the information in messages **135** to produce a result, such as presenting the information in the input packets to a user. In other embodiments described below, the actions performed by packet decoder **110** as a result of processing packets include executing subroutine calls and other program statements specified in protocol specification **140**, or updating internal state values (variables) in the protocol decoder itself.

The general structure shown in FIG. **1** is used in a variety of applications. In one exemplary application, communication processing device **100** accepts digitized multimedia information as data signal **125** according, for instance, to an MPEG standard. The multimedia information may include a multiplexed video, audio, and other data. Packet detector **120** finds individual packets (or "frames") based, for instance, on synchronization data in data signal **125** or on electrical characteristics (e.g., voltage levels) of the data signal between packets. Packet detector **120** sends a finite length bit sequence to packet decoder **110** for each packet it finds. In this exemplary application, some packets may contain audio data in one format while other packets contain video data in another packet format. Some of the video packets may indicate that they are the start of a new video frame, while other video packets may contain addition data for a current video frame. Packet decoder **110** processes the bit stream for each packet it receives from packet decoder **120** in turn. For each packet, if the packet's structure matches the structure of packets described in protocol specification **140**, packet decoder **110** outputs typically one or more messages **135** to message processor **130**. Each message **135** has a type, and in general, includes a number of parameters that are determined by packet decoder **110** from the input bit stream for the packet being processed. To illustrate the types of messages generated in the exemplary case of multimedia decoding, the messages may functionally include "create new audio stream (stream id)," or "new audio samples for data stream (stream id, data)." Message processor **130** receives these messages, and acts on them using the received information, for example, by displaying video on a monitor and playing the audio on speakers.

Referring to FIG. **2**, a second general view of a number of other alternative embodiments of the invention is similar to that shown in FIG. **1**. In these embodiments, communication processing device **200** includes a packet detector **120** and packet decoder **110** as in communication device **100** (FIG. **1**). In addition, communication processing device **200** includes a packet generator **210**, which forms packets that have formats defined by protocol specification **140**, and a packet constructor **220** that accepts a packet sequence from packet generator **210** and forms a data signal **225** that includes the packets as well as indicators in the data signal of the boundaries between packets. As with data signal **125**, which is input to the device, data signal **225**, which is output from the device, may alternatively indicate packet boundaries in the output data stream or using characteristics of the signal itself.

Communication processing device **200** also includes a state machine **230**. State machine **230** accepts messages **235** from packet decoder **110** and maintains a stored state based on past input packets. After packet decoder **110** completes processing a packet that is provided to it by packet detector **120**, and has issued all the messages that are based on that processing, it does not necessarily maintain any history or memory of that packet. State machine **230** on the other hand can maintain such a history. In response to messages **235** that it receives from packet decoder **110**, and on its stored state, it issues messages **245** to packet generator **245** and updates its stored state. In addition, packet decoder **110** passes messages **240** directly to packet generator **210**. Such direct messages can be used by packet generator **245** to generate an output packet, such as an acknowledgment packet, while packet decoder **110** is still processing an input packet.

The structure shown in FIG. **2** is used in a variety of applications. In one exemplary application, communication processing device **200** accepts a data signal **125** that encodes an information stream according to a first format (or protocol) and produces a new data signal **225** that encodes the same information stream according to a second format (protocol), which is different than the first.

Also, although communication processing device **200** is illustrated with a single input data signal **125** and a single output data signal **225**, in various alternative embodiments there are multiple of each. Also, communication processing device **200** may be coupled to another communication device, and accept data signal **125** from that device and provide data signal **225** back in return. In this latter case, for instance, packet generator **210** is responsible for generating acknowledgement packets when data packets are received from the other device.

2 SOFTWARE EMBODIMENT (FIGS. 3-4)

Various embodiments of the invention are software-based, hardware-based, or use a combination of hardware and software. The description that follows is directed at software embodiments in which packet decoder **110**, message processor **130**, state machine **230**, and packet generator **210** are implemented as software modules that execute on a general purpose programmable processor or device controller. Several alternative embodiments, both software- and hardware-based are described in Section 5.

Referring to FIG. **3**, a software-based embodiment of the general type shown in FIG. **1** makes use of protocol specification **140** to generate executable software **340**. Executable software is executed on a processor **360** in communication processor **100**. In this embodiment, communication processor **100** includes processor **360**, which is used to execute executable software **340**, an input interface **365** for generating packet sequence **115**, and working storage **370**, which is used by processor **360** while running executable software **340**.

Executable software **340** is generated from protocol specification **140** in several steps. First, a specification compiler **310** accepts protocol specification **140** and generates packet decoder source code **320**. For instance, specification compiler **310** accepts protocol specification **140** in a syntax described below in Section **Error! Reference source not found.** and produces packet decoder source code in the syntax of the C++ programming language. In addition to protocol specification **140**, message processing source code **325**, for instance also specified in the syntax of the C++ programming language, defines how individual messages generated by packet decoder **110** will be processed. Finally, communication processor source code **315** includes a specification of overall routines to be executed by the communication processing device, for example, including input routines to accept packet sequence **115** and routines to invoke the routines defined in packet decoder source code **330**.

A source code compiler **330**, for example a C++ language compiler and associated link editor, accepts communication processor source code **315**, packet decoder source code **320**, and message processor source code **325**, and produces executable software **340**. Executable software **340** is transferred to a software storage **350**, for instance a magnetic disk or a semiconductor storage in communication processing device **110**, for execution by processor **360**.

Referring now to FIG. **4**, in one software-based embodiment, communication processor executable software **340** includes three modules. These are packet decoder module **420**, which corresponds to packet decoder source code **320** (FIG. **3**), message processor module **425**, which corresponds to message processor source code **325** (FIG. **3**), and communication processor module **415**, which corresponds to communication processor source code **315** (FIG. **3**). A routine in communication processor module **145** inputs packet sequence **115**, for example by reading from a hardware register in input interface **365** (FIG. **3**). For each packet it inputs, it calls a main routine in packet decoder module **420**. Packet decoder module **420** processes the packet, and calls a number of message processors **435**, which are implemented as subroutines in message processing module **425**. Each of these subroutine calls corresponds to passing a message between packet decoder **110** and message processor **130** in FIG. **1**. In operation, message processors **435** are generally associated with occurrence of particular fields in an input packet, and they are called with a parameter that holds the particular value of the field in the input packet.

In the software embodiment described about in relation to FIGS. **3-4**, passing messages between packet decoder **110** and message processor **130** (FIG. **1**) corresponds to software in packet decoder module **420** (FIG. **4**) making subroutine calls to routines in message processor module **425**. Alternative software embodiments do not necessarily make use of such a subroutine call communication mechanism. For instance, a message queue can used whereby code in packet decoder module **130** puts messages in the queue and routines in message processor module **425** dequeue the messages. Alternatively, in an event-driven programming approach, different message processors **435** are associated with different message types, and are invoked automatically by a central messaging service when messages of their associated type are sent.

3 PROTOCOL SPECIFICATION

A particular embodiment of the syntax used for protocol specification **140** is described in this section. Alternative embodiments may use somewhat different syntax to achieve equivalent results. For instance, alternative ways of associating particular messages or message processor routines with occurrence of fields in an input packet may be used.

Referring back to FIGS. **1-2**, communication processing devices **100** and **200** make use of a protocol specification **140** for processing packets in input data signal **125** and for creating packets form output data signal **225**. In the software embodiment described about with reference to FIGS. **3-4**, protocol specification **140** is used to generate executable software **340** (FIG. **3**) that is executed of a software-based implementation of communication processing device **100**.

Protocol specification **140** includes a specification of allowable packet formats (or structures), including, for example, lengths of data fields and allowable values for those fields. In general, protocol specification **140** includes a hierarchical description of allowable packet formats. A packet format can be described as a succession of sub-packets or data fields, and each sub-packet can be further described as a succession of still other sub-packets and data fields, until the entire packet is accounted for with data fields. Protocol specification **140** includes definitions of the packets and data fields. Data fields include specifications of the number of bits allocated to the field, and optionally an association of numeric values and symbolic names. Packet and sub-packet definitions include specifications of allowable sequences of sub-packets or data fields.

In the description of the syntax of protocol specification **140** that follows, elements in square brackets ("[. . .]") are options, boldface elements are keywords of the specification language, italicized elements represent parameters or other defined elements, and elements bracketed by parentheses and separated by vertical bars ("(. . . | . . .)") indicate choices of elements.

At the top level of a protocol specification, the syntax of protocol specification **140** includes a **packet** statement that has the following syntax:

[*modifier*] **packet** (*argument*) [{*definition*}]

where *argument* includes a name, and optionally maximum length of the packet with the syntax

argument = *qualified_name* [, *length*]

and *modifier* determines the units of *length* and can be one of **bit**, **octet**, **auto**, **zstr** (zero terminated string), or **str** (string). The structure of the packet is contained in the definition portion, which is described below.

In the simplest situation, a packet is defined as a fixed length bit sequence, such as

packet sample ("sample name", 80)

which indicates that a packet always has exactly 80 bits, and is named "sample name."

More typically, a packet includes sub-elements. The *definition* section specifies these sub-elements. For example, a **field** statement which has the following structure is used:

[*modifier*] **field** (*argument*) [{*definition*}]

The field statement is similar to the packet statement, except that a field cannot be defined in terms of other packets and fields. That is, it is a terminal element of the grammar that specifies the position of a value encoded in a packet.

To illustrate the use of **field** statements, a sample packet can be specified as follows:

```
packet sample ("sample one", 80 ) {
     field("first field",32)
     field("second field",32)
     field("third field",16)
}
```

The *definition* portion of a **field** statement can be used to associate values, such as numeric constants, with symbolic names that are passed as the parameters of the messages corresponding to that field. The *definition* portion of the statement is also used to define the action the packet decoder should take when it encounters this field.

As an illustration of use of the *definition* portion of a **field** statement to associate values with symbolic names, the definition of the third field in the example above can be replaced with

```
          field("third field",16) {
               alt{1: "value one" 2: "value two"
                    3: "value three" rest: "another value" }
          }
```

so that if a packet is processed in which the last 16 bits of the 80 bit packet have the value 1, the message "third field(value one)" is sent. The **rest** entry corresponds to a default if none of the enumerated values is chosen.

The *definition* portion of a packet or field statement can include a repetition of a sequence of one or more fields or nested sub-packets. For example, the *definition* portion can include the expression

```
          repeat{ field("repeated field a",8)
                  field("repeated field b",8) }
```

to signify that the fields "repeated field a" and "repeated field b" alternate until the data in the packet is accounted for.

The definition of nested packets can be included within a definition, or can be specified separately, thereby making the specification more readable, and, if the same sub-packet is used in several places, centralizes the definition of that sub-packet.

Field values can be used with the **var** construct in place of parameters such as field lengths, and can be used in arithmetic expressions in which a value is computed. Such a use is shown in the following example

```
     packet sample ("sample two") {
          field("packet byte length ",16)
          field("payload",var("packet byte length)*8-16)
```

```
    }
```

Field values can also be used to determine the format of subsequent portions of a packet. For instance, in the following example, the value of an initial field determines the format of subsequent portions of the packet:

```
    packet sample ("sample three") {
        field("payload type",8)
        alt(var("payload type")) {
            0: packet("subpacket type zero")
            1: packet("subpacket type one")
        }
    }
```

Although in many cases, packets can be processed in bit sequence order, that is, the structure of future bits in a packet depends on values, if any, that occur in past bits. When this is not the case, the protocol specification allows a "lookahead" syntax. In particular, **la**(*offset*,*length*) is a value that starts *offset* bits from the current field and has a length *length*.

Also, there are situations in which it is not possible or straightforward to predict which of several possible packet formats are consistent with an input bit sequence. However, considering the entire packet as a whole, only some packets are consistent with the values. The **any** construct signifies that one or more or the definitions may account for the data in the packet, but no messages are sent unless the entire packet is consistent with the structure. In the case that multiple of the formats are consistent with the data, the first listed is chosen. An example of use of the any construct is as follows:

```
packet sample ("sample four") {
     alt {
          packet("packet type zero")
          packet("packet type one")
     }
}
```

The *definition* portions of **field** statements are also used to specify the actions that the packet decoder is to take when it encounters a field. An arithmetic assignment statement or subroutine call can be specified using variables corresponding to field values. C++ operators are enclosed in <: and :> brackets, and field variables are referenced using the var() construct described above. For example, the statement

```
var("fielda")<:=:> var("fieldb") <:+:> var("fieldc")
```

sets the value of the fielda field to be the sum of the values of the fieldb and fieldc fields.

A second example of an action specification is a call to a subroutine, for example, specified as

```
<:ActionSubr(:> var("fielda") <:):>
```

for a call of the subroutine named ActionSubr with its argument being the value of the fielda field.

In the above description, field names are indicated as strings. The specification syntax uses a nested packet and field names to fully specify a field. For example, the field "a field" in a packet named "the packet" is fully specified as "the packet":"a field". A field name that is prefixed with a colon signifies that it is already a fully qualified name, that is, it is not prefixed by the higher level packet names.

The packet specifications are object-oriented in that the scope of field names is local to the packet (or sub-packet) being defined. This allows the same packet definition to be used repeatedly in a protocol without having conflicting field names.

4 EXEMPLARY PROTOCOL SPECIFICATION (FIGS. **5-9F**)

In order to illustrate the form of a protocol specification, a portion of the specification of packets in a ITU-T Q.2931 (B-ISDN Application Protocol) communication protocol is described. In particular, the protocol includes a class of packets called "information elements." Within this class of packets, one particular packet type is a "Broad-band Bearer Capability" packet. In the description below, the specification of the class of information element packets is described, as well as a specification of the particular broad-band bearer class packet.

Referring to FIG. **5**, the general format of an information element packet **500** includes a series of 8-bit units (bytes) each illustrated as one row in the figure. The first byte is an "identifier" **510** that specifies the type of the information element. The next byte **520** includes additional fields. The next 16 bits, bytes **530** and **532**, is "contens len," which is the entire length of packet **500**. This is followed by the contents **540** itself, which in general includes multiple bytes. The format of contents **540** depends on the value of "identifier" **510** in the first byte of packet **500**.

Referring to FIGS. **6A-6B**, a specification of this packet is shown as it appears in protocol specification **140** (FIGS. **1-2**), including associations of particular values of fields with symbolic names appropriate to the protocol. Lines **100** (FIG. **6A**) through **177** (FIG. **6B**) define the format of information element packet **500** (FIG. **5**). Lines **101** through **131** define the first 8-bit field, identifier **510** (FIG. **5**). In addition to naming the field and specifying the length of the field to be 8 bits at line **101**, lines **102** through **130** associate particular values of the file with symbolic constants. When the packet decoder processes the first byte of an input packet according to this specification, it sends an "identifier" message with the parameter being the symbolic names associated with the actual value. Lines **132** through **142** similarly define the fields in the second byte **520** of information element packet **500**. Line **143** both defines the next 16-bit field, "contens len," and also specifies using the **len** construct that the entire information element packet has a bit length specified by this field.

Turning to FIG. **6B**, the remainder of the protocol specification uses an **alt** construct to specify that the remainder of the packet is a sub-packet, and that the particular sub-packet type depends on the value of "identifier" which was located at the first byte of the packet. Note that at line **153**, the specification indicates that if identifier is equal to 0x5e (01011110_2) then the remainder of the packet is a "broad-band bearer capability" packet.

Turning to FIG. **7**, a broad-band bearer capability information element **700** includes a first byte **710** in which identifier equals 0x5e, and bytes **720**, **730**, and **732** of the same form as in the generic information element packet **500** (FIG. **5**). Bytes **740**, **750**, and **750** are formatted according to the "broad-band bearer capability" protocol specification.

Turning to FIG. **8**, the broad-band bearer capability packet (a sub-packet of an information element packet) is specified using similar specification constructs as shown in FIG. **5**. Lines **101** through **104** specify a byte **740** (FIG. **7**), the first byte of the contents which is specific to a broad-band bearer capability packet. Lines **105** through **117** define the format of a next byte **750** (FIG. **7**) which is present only if the "ext bit" field **742** (FIG. **7**, specified at line **101**) of the first byte **740** is equal to 0. Lines **118** through **127** define the format of the last byte **760**, which is always present.

Referring back to FIG. **3**, protocol specification **140** is processed by specification compiler **310** to produce packet decoder source code **320**, which is later combined with message processing source code **325** to form executable software **340**. Referring to FIGS. **9A-G**, portions of the source code is illustrated. Referring to FIGS. **9A-C**, the protocol specification shown in FIGS. **6A-B** for the "information element" packet type is compiled into the C++ language to form the subroutine

```
C$Q_2931_Signaling::PP$information_element()
```

which is a method of the C$Q_2931_Signaling object class. This subroutine begins at line **100** in FIG. **9A**. Referring to lines **104-105**, the value of the "identifier" field is first obtained using the Processfield() call, and then the value of the field is stored in the global variable V$FP$identifier. In line **105**, the message processing function FP$identifier() is called with the parameter value for the identifier field in the packet. This procedure of obtaining field values and the calling the appropriate message processing function is repeated in lines **160-117**, corresponding to lines **132** through **143** in the specification in FIG. **6A**. At line **118** in FIG. **9A**, the **len** construct used in the protocol specification is translated to the SetPduLen() call which resets the length of the packet being processed. The remainder of the PP$information_element() subroutine corresponds to the **alt** construct at lines **144** through **177** in the protocol specification in FIG. **6B**. In particular, lines **144** and **145** correspond to line **157** in FIG. 6B, which corresponds to the special case of a broad-band bearer capability information element. At line **145** in FIG. **9B**, PP$information_element() calls PP$broad_band_bearer_capability() to further process the packet if the value of identifier is 0x5e.

In this example, no actions are explicitly specified in the definition portions of the field specifications. As an option, specification compiler **310** generates implicit actions for each field, corresponding to a call to a subroutine that prints out the content of the field. Using this option, specification compiler **310** essentially produces a protocol analyzer (or "sniffer") that can be used to monitor communication sent according to the specified protocol.

Turning now to FIGS. **9D-E**, an example of a message processing routine, in this case for the identifier message, is shown. This routine is called from line **105** in FIG. **9A** to process the identifier field. In the example in FIGS. **9D-E**, the routine PrintName() is called to output the symbolic name associated with the value of identifier. Other message processing routines would act on the value in other ways.

Turning to FIG. **9F**, the PP$broad_band_bearer_capability() routine at lines **215** through **256** corresponds to the "broad-band bearer capability" protocol specification at lines **100** through **128** in FIG. **8**. As in the PP$information_element() routine, field values are each obtained in turn by a call to ProcessField() and then stored in a global variable, for example in lines **219** and **220** for the "ext bit" field.

5 ALTERNATIVE EMBODIMENTS

Other software-based embodiments, which use the same protocol specification syntax, use different approaches to communicating the field values in an input packet to the message processor (see FIG. **1**), or to a state machine and a packet generator (see FIG. **2**). For instance, rather than passing field values a parameters in messages or subroutine calls, the values can be passed through a shared field storage in which field names are associated with field values.

In other embodiments, rather than generating source code from a protocol specification, which is in turn compiled into executable software, the protocol specification is preprocessed to produce a binary form and which is then interpreted by software in the communication processing device at run time. In one example of preprocessing, the protocol specification, which is input as readable text, is processed into a data structure that more efficiently encodes the same information.

In other embodiments, rather than using a general-purpose processor or controller to process the input packets based on the protocol specification, a customized processor is used. The customizations include instructions that are specially tailored for processing the input packets. These tailored instructions are called directly in source code obtained by processing the protocol specification, or are called by an interpreter that processes the protocol specification, or an equivalent data structure, at run time.

In other embodiments, customized hardware is designed from the protocol specification. For instance, rather than processing the protocol specification to produce a source code in a procedural programming language, the protocol specification is translated into a hardware description language (e.g., Verilog) that is then processed by hardware design software to specify customized integrated circuits.

Still other embodiments use a combination of generation of program source code, data structures describing the protocol specifications, and hardware specification from the protocol specification.

Other embodiments make use of parallel processing to implement the packet decoder. For example, packet decoder module **420** (FIG. **4**) can be implemented on a multiple-processor computer. When a sub-packets of known length is encountered by the packet decoder, the processing of that sub-packet is performed on another processor in parallel while processing of the packet continues with the portion following that sub-packet. In order to ensure proper interpretation of incoming packets, the protocol specification can optionally include statements that indicate that particular sub-packets can be safely processed in parallel.

Another view of the process of creating a hardware or software implementation according to a protocol specification is to arrange the nested sub-packets and fields in a tree structure, a direct solution tree, with actions associated with leaves and possibly internal nodes of the tree. Referring to FIG. **10**, a portion of such a tree structure are shown for the example specification in FIGS. **6A**-B and FIG. **8**. A root node **1010** corresponds to any type of input packet. A branch **1012** corresponds to a information element packet, defined at line 100 in FIG. **6A**. Branch **1012** terminates at a node **120**, from which branches originate corresponding to the various sub-packets and fields of an information element packet. For example, a branch **1022** corresponds to an identifier field (line 101, FIG. **6A**), a branch **1022** corresponds to the action identifier field (line 142, FIG. **6A**), and a branch **1026** corresponds to the broadband bearer capability sub-packet (line 158, FIG. **6B**). Branch **126** terminates at a node **130** which is the root of branches corresponding to the sub-elements of a broadband bearer capability sub-packet. For example, branch **1032** corresponds to the ext bit field (line 101, FIG. **8**), branch **1034** corresponds to the bearer class field (line 103, FIG. **8**), and branch **1036** corresponds to the traffic type field (line 107, FIG. **8**). Note that only a small number of paths through such a tree are taken for any one packet, and the same path may be taken multiple times, for example, if the same sub-element of a packet is repeated multiple times.

In various embodiments, packet detector **120** (see FIG. 1) uses hardware approaches, software approaches, or a combination of hardware and software approaches to determine the boundaries of individual packets. In addition, packet detector **120** can alternatively also perform a packet assembly function in which it detects multiple packets, but it assembles the individual packets to form a larger packet before forwarding that larger packet to packet decoder **110**. An example of such packet assembly may be found in an ATM-based system in which packets each split into a series of ATM cell payloads, and then the packet detector reassembles the larger packets before further decoding. In the case of electrical characteristics of data signal **125** signifying packet boundaries, packet detector **120** includes electronic circuitry for identifying the packets, and for converting the content of the packet into a finite-length digital bitstream of the information in the packet. In the case that packet boundaries are identified in the bit stream itself, packet decoder **110** takes a continuous digital bit stream transmitted in data signal **125** and sends finite length subsequences of bits to packet decoder **110**. Packet decoder **110** receives the bit stream, and processes the content of the bit stream.

In the description in Section **Error! Reference source not found.** above, a particular syntax for the protocol specification is described. In other embodiments, other specification can be used. For example, other types of phrase-structured grammars can be used to describe the nested structure of packets, sub-packets, and fields in a packet. As in the above embodiment, the packet decoder parses the input packet based on the grammar to determine the nested boundaries of packets (phrases, non-terminal elements) and fields (terminal elements), and then issues messages based on the resulting parse of the input packet.

Related embodiments of the invention are applicable in areas other than data communication in which processing of information sequences with complex structures is required. One such embodiment is in the area of chemical analysis in which an automated chemical analyzer creates a sequential description from a sample of a chemical using well known chemical analysis techniques. This sequential description is then fed to a "decoder" that accepts a chemical specification that has a similar form to the protocol specification described in other embodiments. In particular, the chemical specification includes definitions of typically nested constituents that may be found in the sequential description, as well as associated actions to take when those constituents are found. In another embodiment, a similar approach can be taken to analyze complex DNA sequences using a DNA specification that is analogous to the protocol specification used in the communication-related embodiments.

It is to be understood that while the invention has been described in conjunction with the detailed description thereof, the foregoing description is intended to illustrate and not limit the scope of the invention, which is defined by the scope of the appended claims. Other aspects, advantages, and modifications are within the scope of the following claims.

What is claimed is:

1. A method for processing a data signal comprising:

accepting a protocol specification that includes specification of a plurality of elements, each specification including a length and a name, wherein the specifications of at least some of the elements are in terms of sequences of other of the plurality of elements, and the specification of at least some of the elements includes a specification of an action;

accepting a series of data packets formed from the data signal;

for each accepted packet, associating portions of the input packet with elements specified in the protocol specification; and

for each of the associated portions of the input packet, performing actions included in the specification of elements associated with that portion of the input packet.

2. The method of claim 1 wherein the specification of an action includes a specification of a programming language statement, and wherein performing actions included in the specification of elements includes executing the programming language statement.

3. The method of claim 2 further comprising processing the protocol specification to produce executable software, and wherein execution of the software implements the functions of associating portions of input packets with elements specified in the protocol specification and performing actions associated with elements specified in the protocol specification.

4. The method of claim 2 wherein the protocol specification includes an object-oriented specification of elements, wherein names of components of an element are local to that element.

5. The method of claim 2 wherein the protocol specification includes an association of numerical values and symbolic names for an element.

6. The method of claim 1 further comprising processing the protocol specification to produce a hardware description, and wherein performing actions included in the specification of elements includes sending a message identifying a specified action.

COMMUNICATION PROCESSING DEVICE

Abstract

A method for processing a data signal, for instance, a data signal encoding a data bit stream which carries a sequence of data packets. The method includes accepting a protocol specification that includes specification of a number of elements, each specification including a length and a name, and optionally internal structure and actions. For instance, the elements are sub-packets or data fields. The method also includes accepting a series of data packets and for each accepted packet, associating portions of the input packet with elements specified in the protocol specification. For each of the associated portions of the input packet, the method includes performing actions included in the specification of elements associated with that portion of the input packet, for example by use of a subroutine call or passing a data message.

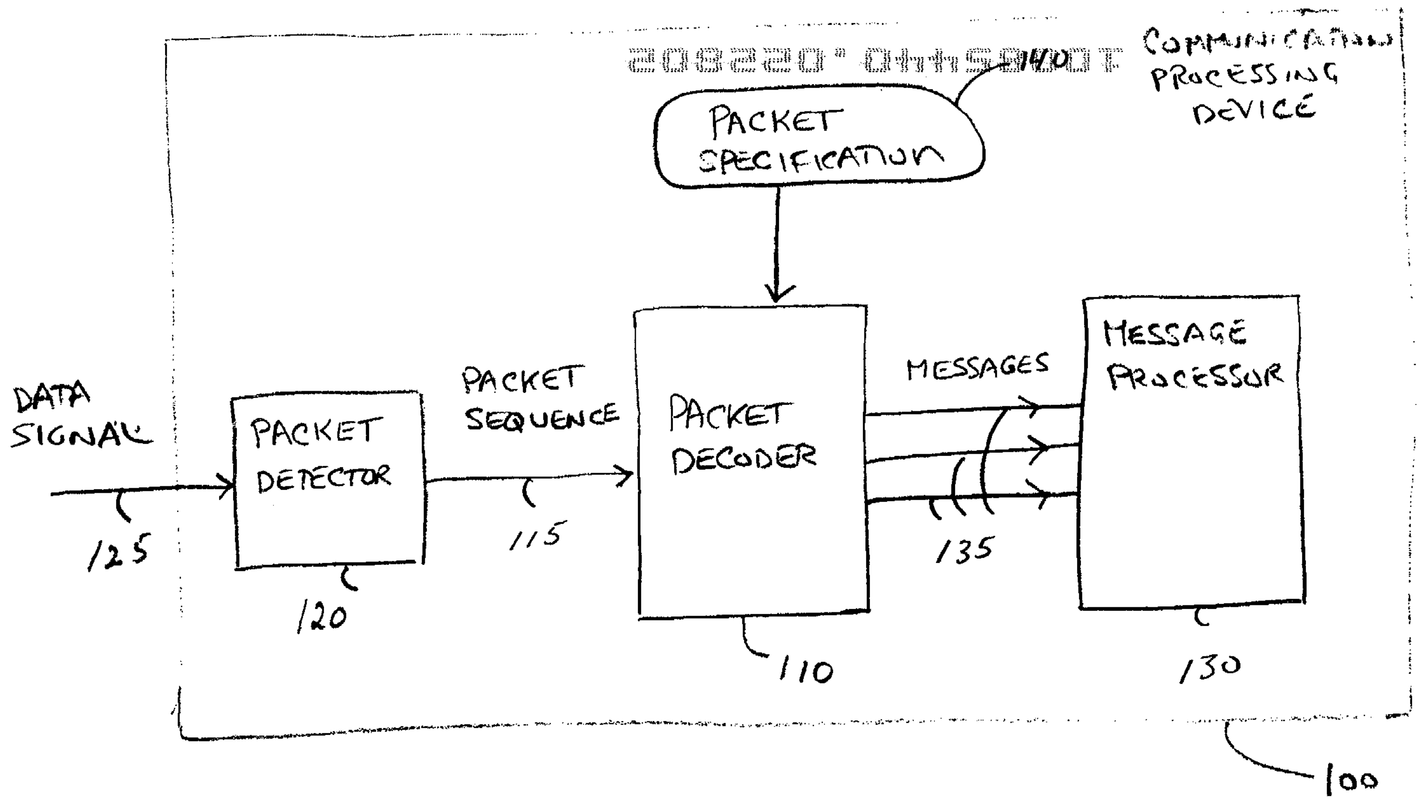

COMMUNICATION PROCESSING DEVICE
140
PACKET SPECIFICATION
DATA SIGNAL
125
PACKET DETECTOR
120
PACKET SEQUENCE
115
PACKET DECODER
110
MESSAGES
135
MESSAGE PROCESSOR
130
100

FIG. 1

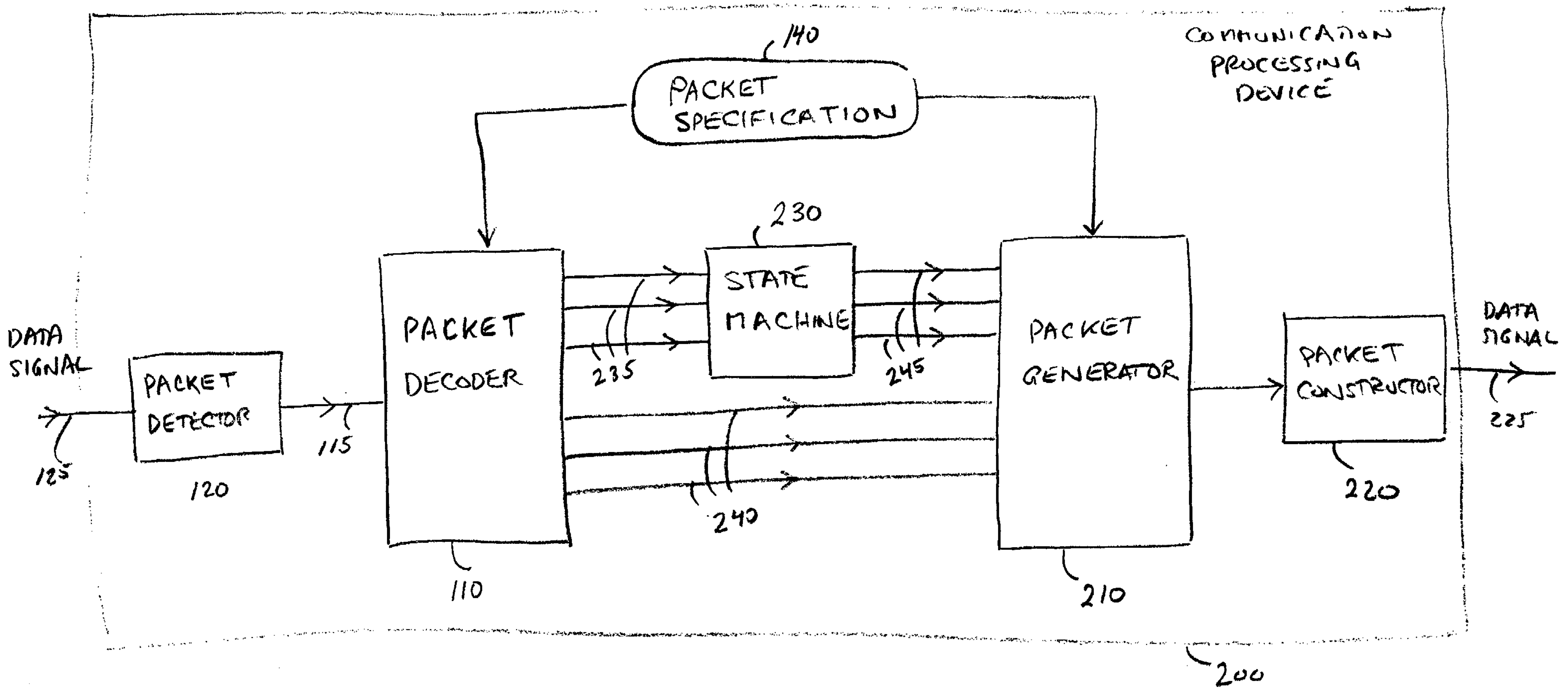
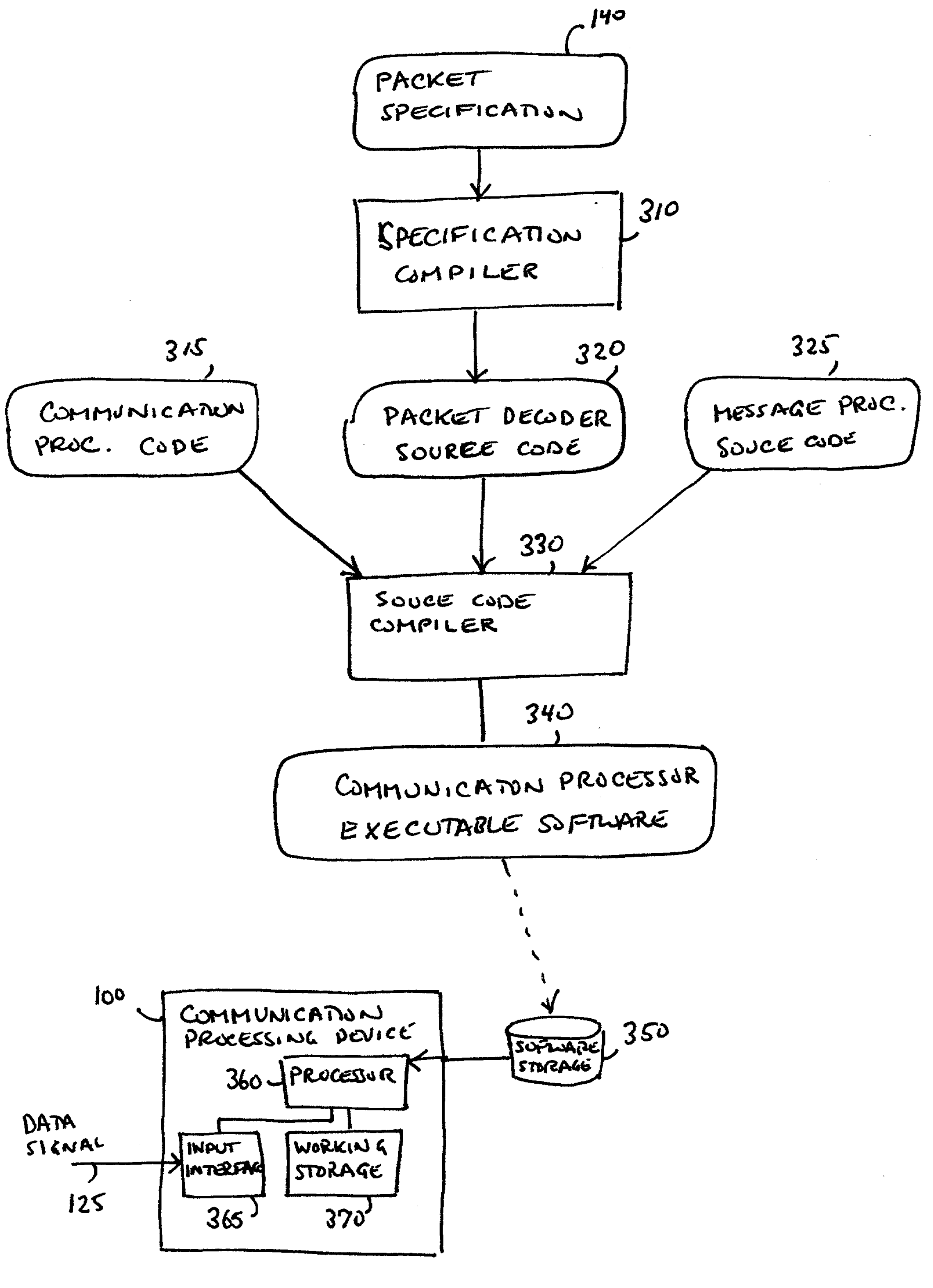

DATA SIGNAL
125
PACKET DETECTOR
120
115
PACKET DECODER
110
140
PACKET SPECIFICATION
230
STATE MACHINE
235
245
240
PACKET GENERATOR
210
PACKET CONSTRUCTOR
220
DATA SIGNAL
225
COMMUNICATION PROCESSING DEVICE
200

FIG. 2



140
PACKET SPECIFICATION
310
SPECIFICATION COMPILER
315
COMMUNICATION PROC. CODE
320
PACKET DECODER SOURCE CODE
325
MESSAGE PROC. SOUCE CODE
330
SOUCE CODE COMPILER
340
COMMUNICATION PROCESSOR EXECUTABLE SOFTWARE
100
COMMUNICATION PROCESSING DEVICE
360
PROCESSOR
DATA SIGNAL
125
INPUT INTERFACE
365
WORKING STORAGE
370
SOFTWARE STORAGE
350

FIG. 3

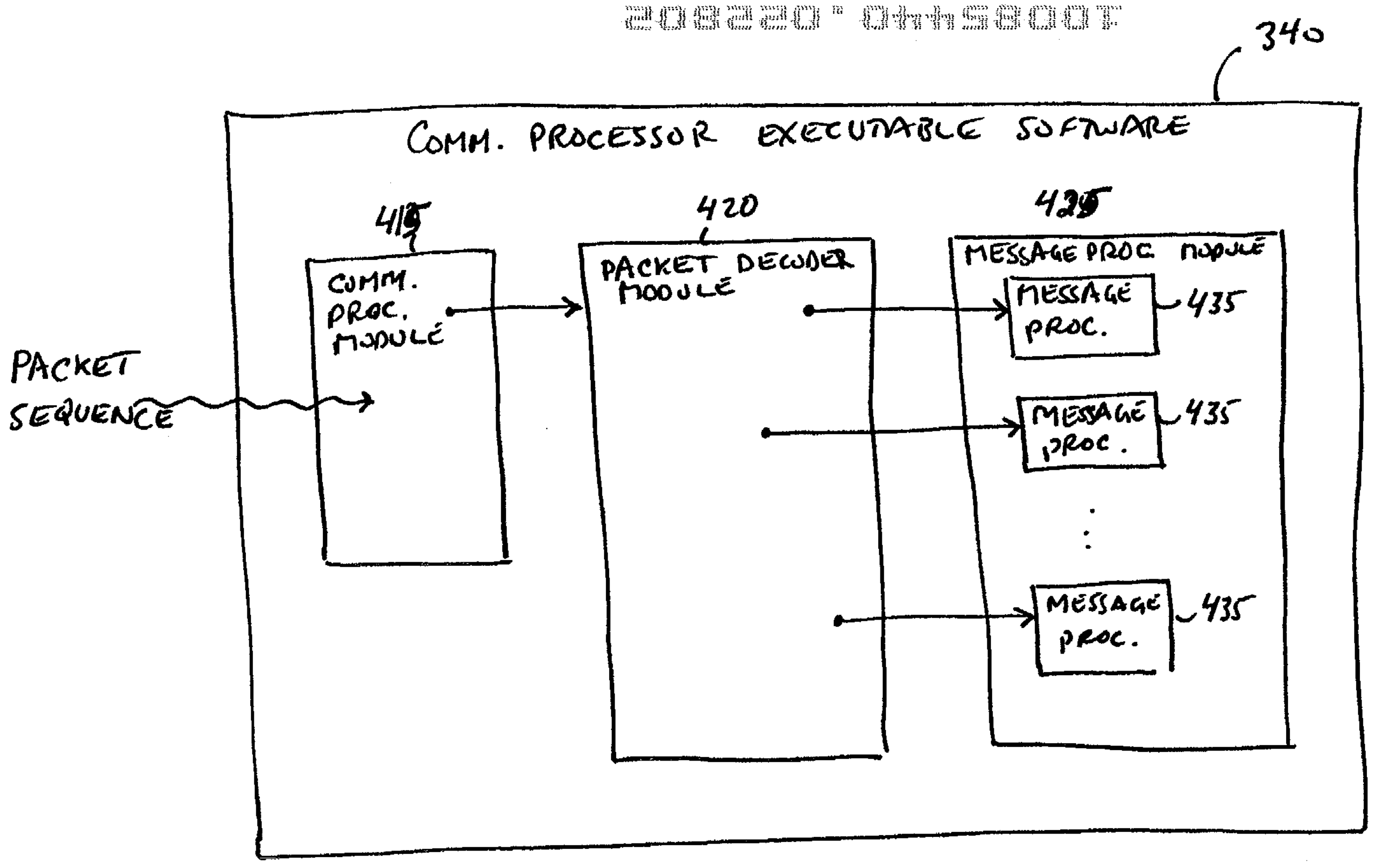
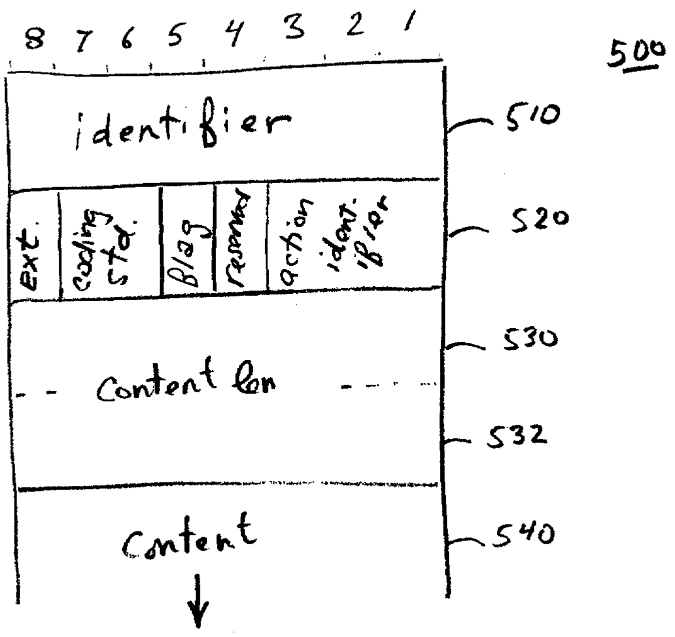

340
COMM. PROCESSOR EXECUTABLE SOFTWARE
415
COMM. PROC. MODULE
PACKET SEQUENCE
420
PACKET DECODER MODULE
425
MESSAGE PROC MODULE
MESSAGE PROC.
435
MESSAGE PROC.
435
MESSAGE PROC.
435

FIG. 4



8 7 6 5 4 3 2 1
500
identifier
510
ext.
coding std.
flag
reserved
action identifier
520
Content len
530
532
Content
540

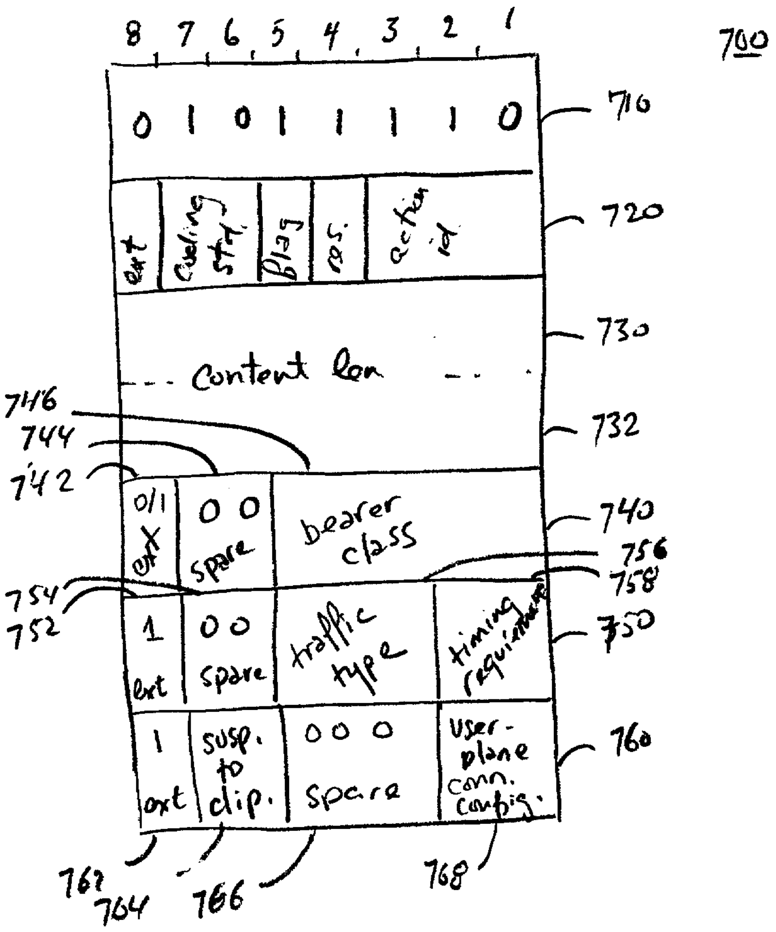
FIG. 5

```
100  packet ("information element") {
101     field(:"identifier",8) {alt{
102      0x04:"narrow-band bearer capability"
103      0x08:"cause" 0x14:"call state"
104      0x1e:"progress indicator"
         .
         .
         .
111      0x5c:"quality of service parameter"
112      0x5e:"broad-band bearer capability"
113      0x5f:"broad-band low layer information"
         .
         .
         .
128      0x7c:"narrow-band low layer compatibility"
129      0x7d:"narrow-band high layer compatibility"
130      rest:"unknown"}
131     }
132     field(:"ext bit")
133     field(:"coding standard",2) {alt{
134      0:"ITU-T standartized coding"
135      1:"ISO/IEC standard"
136      2:"national standard"
137      3:"standard defined for the network present on the network instruction field is
138      not significant"}
139     }
140     field(:"flag")
141     field(:"reserved") {"should be 0x00"}
142     field(:"action identifier",3)
143     len field("contens len",16)
```

FIG. 6A

```
alt(var(:"identifier")) {
      0x04:packet(:"narrow-band bearer capability")          // Q.2931 pg. 79
                                                              // Q.2931 pg. 64
      0x08:packet(:"cause")                                   // Q.2931 pg. 68
      0x14:packet(:"call state")                              // Q.2931 pg. 59
      0x1e:packet(:"progress indicator")                      // Q.2931 pg. 81
  .
  .
  .
      0x5c:packet(:"quality of service parameter")            // Q.2931 pg. 72
      0x5e:packet(:"broad-band bearer capability")            // Q.2931 pg. 51
      0x5f:packet(:"broad-band low layer information")        // Q.2931 pg. 54
  .
  .
  .
      0x7c:packet(:"narrow-band low layer compatibility")     // Q.2931 pg. 80
      0x7d:packet(:"narrow-band high layer compatibility")    // Q.2931 pg. 79
      rest:"unknown"
    }
 }
```

FIG. 6B



8 7 6 5 4 3 2 1
700
0 1 0 1 1 1 1 0
710
ext
cueing step
flag
res.
action id
720
Content len
730
732
746
744
742
0/1 ext
0 0 spare
bearer class
740
756
758
754
752
1 ext
0 0 spare
traffic type
timing requirement
750
1 ext
susp. to clip.
0 0 0 spare
User-plane conn. config.
760
762
764
766
768

FIG. 7

```
100  packet("broad-band bearer capability") {
101   field(:"ext bit")
102   field(:"spare", 2)
103   field("bearer class",5) {alt{
104    1:"BCOB-A" 3:"BCOB-C"  0x10:"BCOB-X" rest:"reserved"}}
105   alt(var(:"ext bit")) {
106    0: field(:"ext bit") field(:"spare",2)
107     field("traffic type",3) {alt{
108      0:"no indication"
109      1:"constant bit rate"
110      2:"variable bit rate"
111      rest:"reserved"}}
112    field("timing requirements",2) {alt{
113      0:"no indication"
114      1:"end-to-end timing required"
115      2:"end to end timing not required"
116      rest:"reserved"}}
117   }
118   field(:"ext bit")
119   field("susceptibility to clipping",2) {alt{
120    0:"not susceptible to clipping"
121    1:"susceptible to clipping"
122    rest:"reserved"}}
123   field(:"spare",3)
124   field("user plane connection configuration",2) {alt{
125    0:"point-to-point"
126    1:"point-to-multipoint"
127    rest:"reserved"}}
128  }
```

FIG. 8

```
void C$Q_2931_Signaling::PP$information_element (char* aname, unsigned a) {
 if( !CurPduLen() ) return;
 ProcessPacketBeg( aname, a );

 V$FP$identifier = ProcessField ( "identifier", 8);
 FP$identifier ( V$FP$identifier );
 V$FP$ext_bit = ProcessField ( "ext bit", 1);
 FP$ext_bit ( V$FP$ext_bit );
 V$FP$coding_standard = ProcessField ( "coding standard", 2);
 FP$coding_standard ( V$FP$coding_standard );
 V$FP$flag = ProcessField ( "flag", 1);
 FP$flag ( V$FP$flag );
 V$FP$reserved = ProcessField ( "reserved", 1);
 FP$reserved ( V$FP$reserved );
 V$FP$action_identifier = ProcessField ( "action identifier", 3);
 FP$action_identifier ( V$FP$action_identifier );
 V$FP$information_element$contens_len = ProcessField ( "contens len", 16);
 FP$information_element$contens_len ( V$FP$information_element$contens_len );
 SetPduLen ( V$FP$information_element$contens_len );

 if ( V$FP$identifier == 0x04 ) {
  PP$narrow_band_bearer_capability ( "narrow-band bearer capability", CurPduLen());

 } else
 if ( V$FP$identifier == 0x08 ) {
  PP$cause ( "cause", CurPduLen());

 } else
 if ( V$FP$identifier == 0x14 ) {
  PP$call_state ( "call state", CurPduLen());

```

FIG. 9A

```
 } else
 if ( V$FP$identifier == 0x1e ) {
  PP$progress_indicator ( "progress indicator", CurPduLen());

.
.
.

 } else
 if ( V$FP$identifier == 0x5c ) {
  PP$quality_of_service_parameter ( "quality of service parameter", CurPduLen());

 } else
 if ( V$FP$identifier == 0x5e ) {
  PP$broad_band_bearer_capability ( "broad-band bearer capability", CurPduLen());

 } else
 if ( V$FP$identifier == 0x5f ) {
  PP$broad_band_low_layer_information ( "broad-band low layer information",
CurPduLen());

.
.
.

 } else
 if ( V$FP$identifier == 0x7c ) {
  PP$narrow_band_low_layer_compatibility ( "narrow-band low layer compatibility",
CurPduLen());

```

FIG. 9B

```
  } else
  if ( V$FP$identifier == 0x7d ) {
   PP$narrow_band_high_layer_compatibility ( "narrow-band high layer compatibility",
CurPduLen());

  } else  {
   PrintName("unknown");
  } ;
  ProcessPacketEnd(aname, a );
} // end of packet processor function definition PP$information_element
```

FIG. 9C

```
void C$Q_2931_Signaling::FP$identifier (unsigned a) {

 PrintName(": ");

 if ( a == 0x04 ) {
  PrintName("narrow-band bearer capability");
 } else
 if ( a == 0x08 ) {
  PrintName("cause");
 } else
 if ( a == 0x14 ) {
  PrintName("call state");
 } else
 if ( a == 0x1e ) {
  PrintName("progress indicator");

.
.
.

 } else
 if ( a == 0x5c ) {
  PrintName("quality of service parameter");
 } else
 if ( a == 0x5e ) {
  PrintName("broad-band bearer capability");
 } else
 if ( a == 0x5f ) {
  PrintName("broad-band low layer information");

```

FIG. 9D

```
 .
 .
 .

  } else
  if ( a == 0x7c ) {
   PrintName("narrow-band low layer compatibility");
  } else
  if ( a == 0x7d ) {
   PrintName("narrow-band high layer compatibility");
  } else  {
   PrintName("unknown");
  } ;
} // end of field processor function definition FP$identifier
```

FIG. 9E

```
void C$Q_2931_Signaling::PP$broad_band_bearer_capability (char* aname, unsigned a) {
 if( !CurPduLen() ) return;
 ProcessPacketBeg( aname, a );

 V$FP$ext_bit = ProcessField ( "ext bit", 1);
 FP$ext_bit ( V$FP$ext_bit );
 V$FP$spare = ProcessField ( "spare", 2);
 FP$spare ( V$FP$spare );
 V$FP$broad_band_bearer_capability$bearer_class = ProcessField ( "bearer class", 5);
 FP$broad_band_bearer_capability$bearer_class (
V$FP$broad_band_bearer_capability$bearer_class );

 if ( V$FP$ext_bit == 0 ) {
 V$FP$ext_bit = ProcessField ( "ext bit", 1);
 FP$ext_bit ( V$FP$ext_bit );
 V$FP$spare = ProcessField ( "spare", 2);
 FP$spare ( V$FP$spare );
 V$FP$broad_band_bearer_capability$traffic_type = ProcessField ( "traffic type", 3);
 FP$broad_band_bearer_capability$traffic_type (
              V$FP$broad_band_bearer_capability$traffic_type );
 V$FP$broad_band_bearer_capability$timing_requirements = ProcessField ( "timing
requirements", 2);
 FP$broad_band_bearer_capability$timing_requirements (
V$FP$broad_band_bearer_capability$timing_requirements );

 } else  ;
   V$FP$ext_bit = ProcessField ( "ext bit", 1);
 FP$ext_bit ( V$FP$ext_bit );
 V$FP$broad_band_bearer_capability$susceptibility_to_clipping = ProcessField (
"susceptibility to clipping", 2);
```

FIG. 9F

```
 FP$broad_band_bearer_capability$susceptibility_to_clipping (
V$FP$broad_band_bearer_capability$susceptibility_to_clipping );
 V$FP$spare = ProcessField ( "spare", 3);
 FP$spare ( V$FP$spare );
 V$FP$broad_band_bearer_capability$user_plane_connection_configuration =
ProcessField ( "user plane connection configuration", 2);
 FP$broad_band_bearer_capability$user_plane_connection_configuration
        (V$FP$broad_band_bearer_capability$user_plane_connection_configuration );

 ProcessPacketEnd(aname, a );
}
// end of packet processor function definition PP$broad_band_bearer_capability
```

FIG. 9G

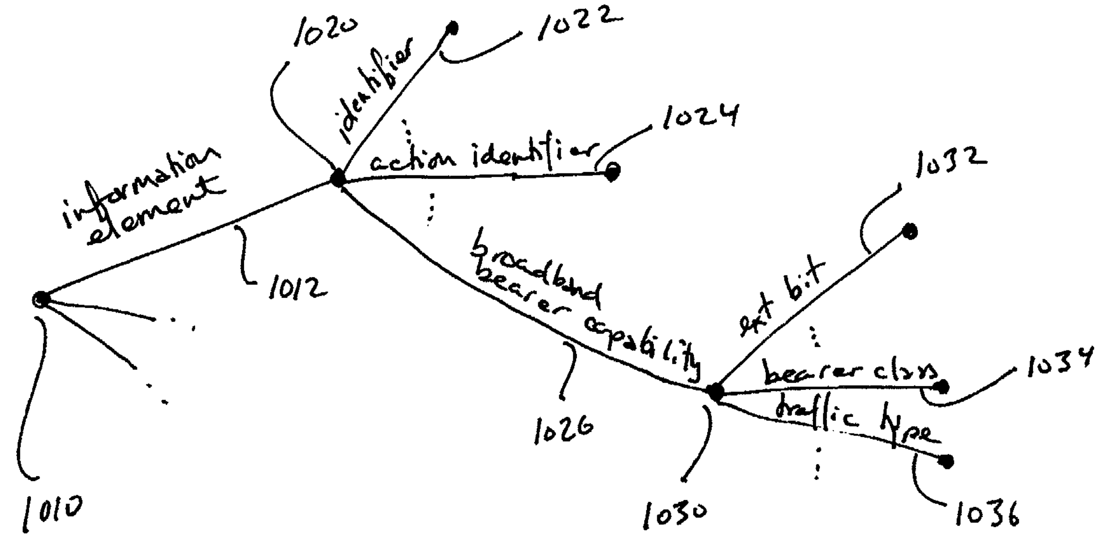

information element
identifier
action identifier
broadband bearer capability
ext bit
bearer class
traffic type
1010
1012
1020
1022
1024
1026
1030
1032
1034
1036

FIG. 10